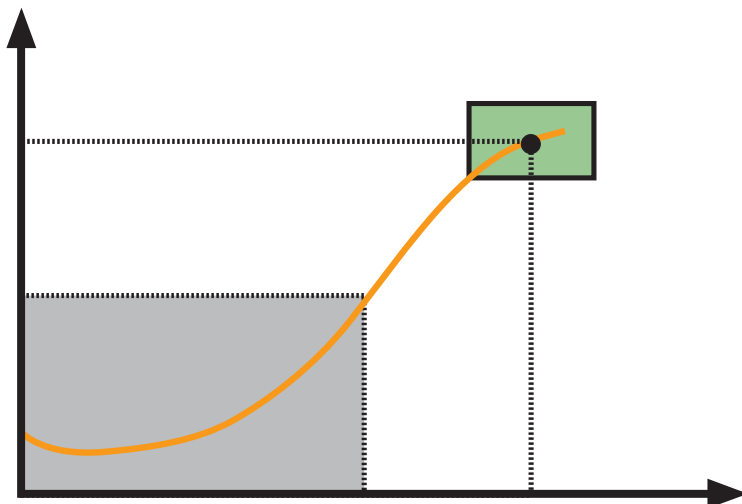


Special Edition

**DEPRAG**

## Screwdriving Technology and Quality Assurance



Screwdriving Technology



Automation



Air Motors



Air Tools



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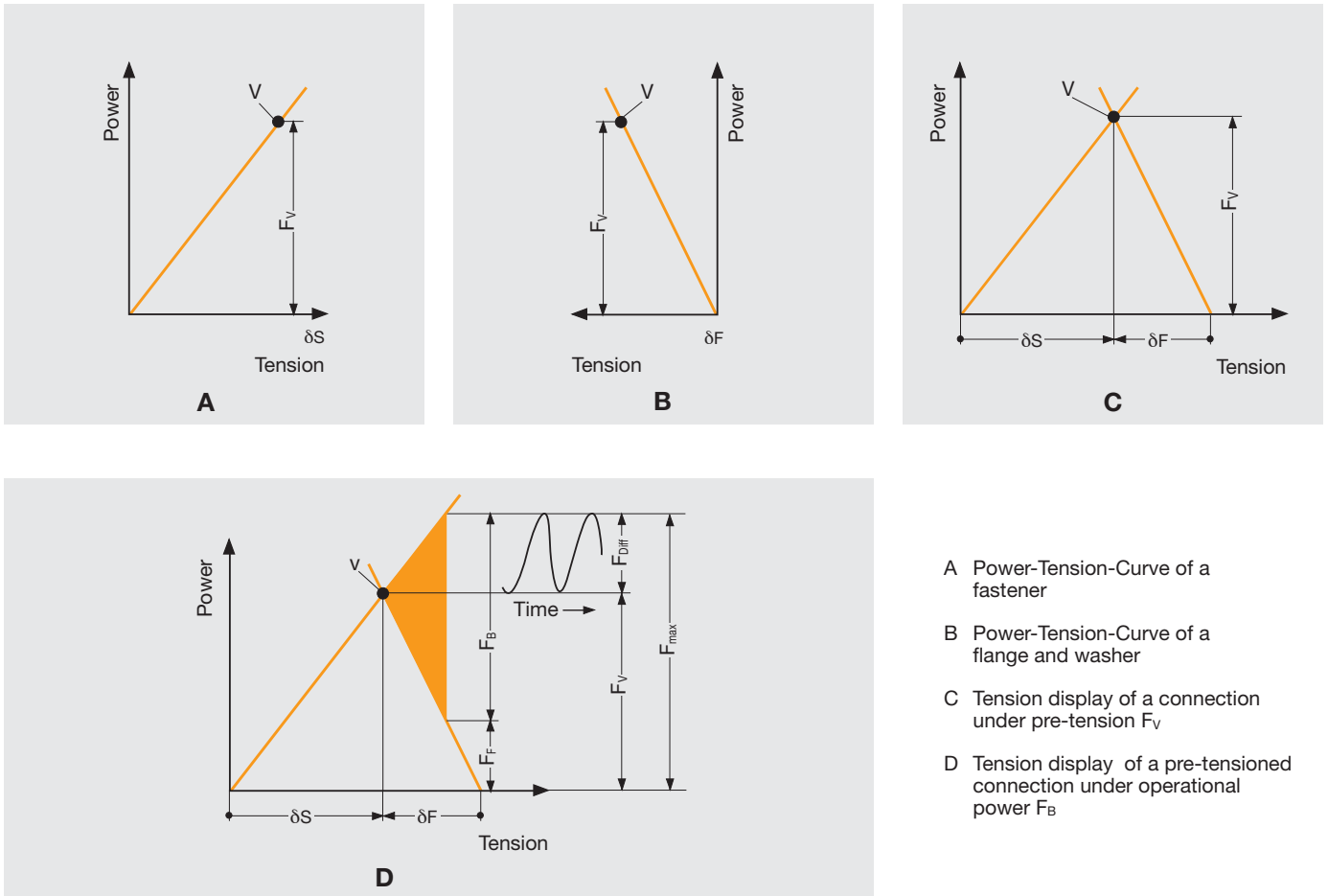
- **Depth**
- **Assembly**
- **Cutting Threads**
- **Drilling**
- **Adjustment**
- **Loosening**
- **Create Pre-Tension**

Picture 1: Assembly Goal

The screwdriving technology is still one of the key elements in many assembly processes. Increasing system complexities, as well as rising demands for technological process control of the highest quality, requires a comprehensive expertise in the

design and the operation of superior screw-driving- and assembly systems.

This special edition is a way to convey to our clients our expertise in regards to theoretical basics and to simultaneously offer a practical application guide.



- A Power-Tension-Curve of a fastener
- B Power-Tension-Curve of a flange and washer
- C Tension display of a connection under pre-tension  $F_V$
- D Tension display of a pre-tensioned connection under operational power  $F_B$

Picture 2: Tension Pictures

## 1. Screwdriving Assembly Requirement

### 1.1 Process Description

Goal of a screwdriving task is either the application of a defined holding strength (pre-load) or the execution of certain adjustment- or dismantling processes. In these cases, the described size is either a longitudinal-measurement (depth in or out) or an angle-measurement (number of revolutions).

The sizes can be acquired directly through the use of NC-measurement systems or indirectly through time. However, the most important application case is the determination of a defined pre-load. The pre-load has to be determined in such a way, that on one hand the intended function is still a given despite the applied operating power

and on the other hand, the allowable load of the screw-connection is not exceeded. Seating processes of a joint and other assembly related fluctuations of the achieved pre-load are just some of the most common problems.

$$M_A = F_M \left[ 0.16 P + \mu_G 0.58 d_2 + \frac{D_{km}}{2} \mu_K \right]$$

$M_A$	=	Tightening torque
$F_M$	=	Assembly Pre-Load
$P$	=	Thread Pitch
$\mu_G$	=	Thread Friction Value
$\mu_K$	=	Head Friction Value
$d_2$	=	Standard Thread Diameter
$D_{km}$	=	Head Diameter

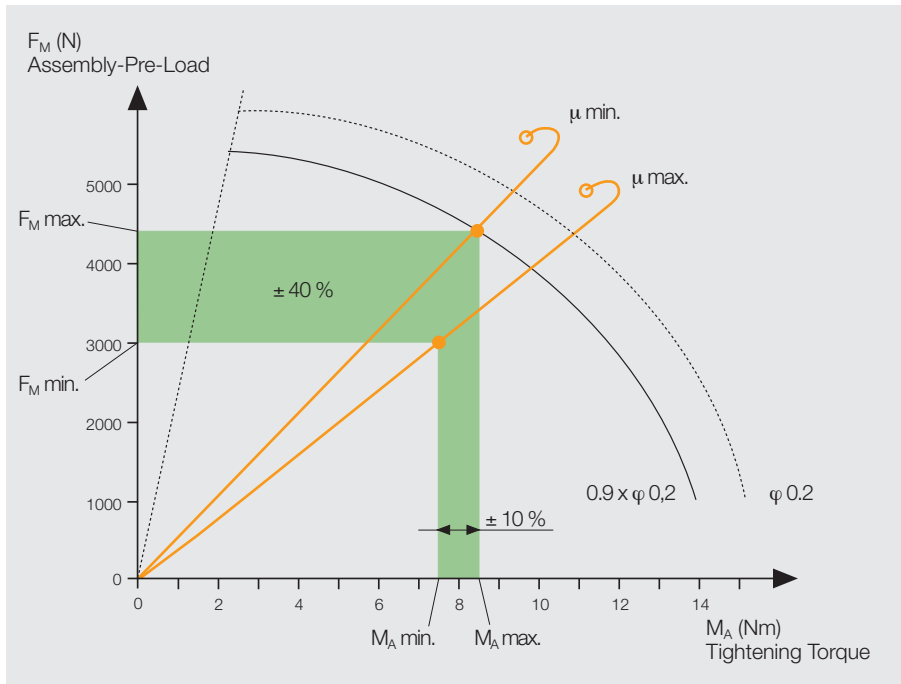
Picture 3: Torque Calculation

The target pre-load cannot be practically acquired during a series assembly process. For the control of the assembly process, one must therefore use indirect measurement sizes, which is normally the tightening torque. The torque can be calculated using the required pre-load in accordance with the formula of VDI-guideline 2230. In addition, further criterions that may be used as guidelines for the assembly process, may be determined, such as torque-angle, assembly times, etc. Tables, such as shown in Picture 4, may be used for further orientation.

In principle, the length-measurement is another indirect measuring-value that could be used for the determination of a pre-load. Such a procedure is very time-consuming and therefore not very commonly used. Because of its practical applicability, torque is still the most commonly used determining factor.

Thread-Description		max. Pre-Tension $F_V$ (N)			max. Tightening torque $M_A$ (Nm)		
		Property Class			Property Class		
		8.8	10.9	12.9	8.8	10.9	12.9
<b>Shaft Screw</b> (Total Friction $\mu_s = 0.08$ )							
Standard Thread	M 4	4350	6150	7400	2.1	2.9	3.5
	M 5	7150	10100	12100	4.2	6	7.1
	M 6	10100	14200	17000	7	10	12
	(M 7)	14800	20700	24900	12	16	20
	M 8	18500	26100	31300	17	24	29
	(M 9)	24700	34700	41600	25	35	43
	M 10	29500	41400	49700	34	48	58
	M 12	43000	60500	72500	60	84	100
M 14	59000	82500	99000	95	135	160	
Fine Thread	M 8 x 1	20200	28400	34100	18	26	31
	M 10 x 1.25	31600	44400	53300	36	51	61
	M 12 x 1.25	48200	68000	81500	64	91	110
	M 12 x 1.5	45400	64000	76500	62	87	105
	M 14 x 1.5	65000	91500	110000	100	140	170
<b>Shaft Screw</b> (Total Friction $\mu_s = 0.125$ )							
Standard Thread	M 4	4000	5650	6750	2.7	3.8	4.6
	M 5	6550	9200	11100	5.5	8	9.5
	M 6	9250	13000	15600	9.5	13	16
	(M 7)	13600	19100	22900	15	22	26
	M 8	17000	23900	28700	23	32	39
	(M 9)	22600	31900	38200	34	47	57
	M 10	27100	38000	45700	46	64	77
	M 12	39500	55500	66700	80	110	135
M 14	54000	76000	91300	125	180	215	
Fine Thread	M 8 x 1	18600	26200	31500	25	35	42
	M 10 x 1.25	29100	40900	49100	49	68	82
	M 12 x 1.25	44600	62500	75000	88	125	150
	M 12 x 1.5	41900	59000	70500	83	115	140
	M 14 x 1.5	60500	85000	102000	140	195	235
<b>Flex Screw</b> (Total Friction $\mu_s = 0.125$ )							
Standard Thread	M 4	2150	3050	3650	1.5	2.1	2.5
	M 5	3650	5100	6150	3.1	4.4	5
	M 6	5200	7300	8800	5.5	7.5	9
	(M 7)	8100	11400	13700	9	13	16
	M 8	10100	14200	17000	14	19	23
	(M 9)	13800	19400	23300	21	29	35
	M 10	16300	22900	27500	28	39	47
	M 12	24300	34200	41000	49	69	83
M 14	33500	47100	56500	79	110	135	
Fine Thread	M 8 x 1	11600	16300	19600	16	22	26
	M 10 x 1.25	18300	25700	30900	31	43	52
	M 12 x 1.25	29100	40900	49100	58	81	97
	M 12 x 1.5	26600	37500	45000	53	75	90
	M 14 x 1.5	39100	5500	66000	90	125	150
	M 16 x 1.5	54500	76500	92000	140	195	235

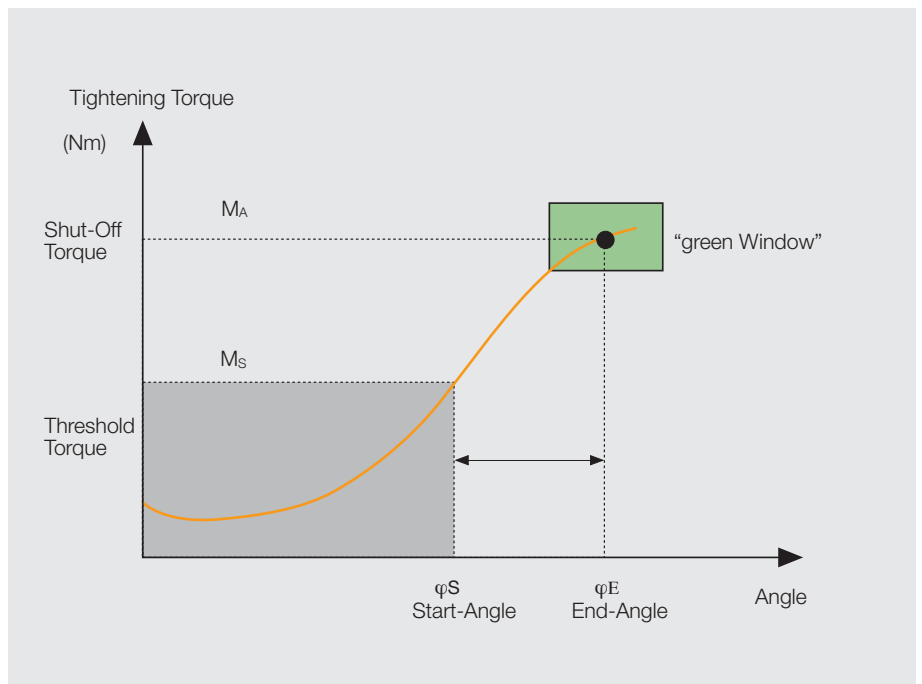
Picture 4: Table Values for pre-load and tightening Torque



Picture 5: Friction Influence during torque-controlled tightening

## 1.2 Torque-Controlled Tightening

The most important factor for tightening of screw joints is always the torque. Also for many other processes, the torque is a controlling factor. The problem with the torque-controlled tightening lays in the fluctuating friction-values. There are two different friction values, the thread-friction and the head-friction. The sum of these fluctuating friction conditions results in up to 50 % and more fluctuation of the pre-load, despite high torque repeatability. This means, that the screw-joint must always be over-dimensionalized, so that the screw joint is not overtightened when an upper deviation occurs but still has enough tightening-strength in case of lower deviation.



Picture 6: Additional Angle Monitoring at torque-controlled tightening

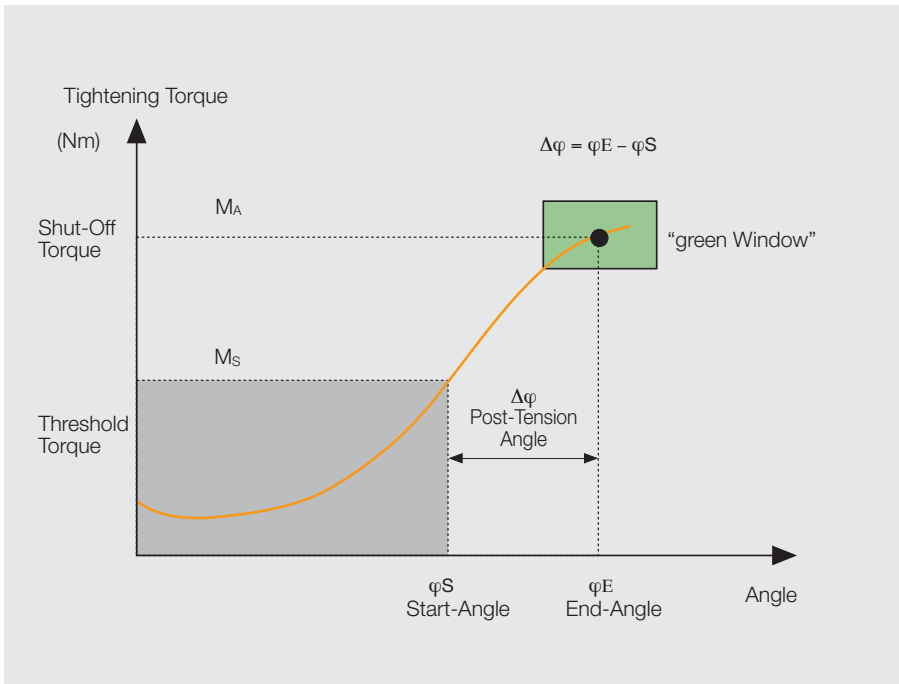
Despite these disadvantages, the torque-controlled tightening process is by far the most commonly used tightening process. This is because of a relative simple technical process. It is the best tightening process for the predominant number of screw joints. As additional variation, it is possible to overlay the torque-controlled tightening process with an angle monitoring process. There, the actual assembly process is enforced unchanged. However, at a certain trigger torque value, the post-tension angle is being controlled. This post-tension angle must be – for an assembly to be determined O.K. – within predetermined limit values and a so-called "green window".

In most application cases however, no essential quality improvements can be obtained by using an additional and essentially more simple supervision of the screw depth. Only in special cases, where for example changing material values on the product may occur, is it necessary to recognize additional errors due to the fluctuation of the post-tension angle.

So one could conceivably discover a missing seal because of a post-tension angle being too short or an insufficiently hardened part because of a post-tension angle being too long. Usually the trigger torque value, from which the angle is counted, should lie between 20 % (hard screw-joint) and 80 % (soft screw-joint) of the final torque value.

Practical experience has shown, that frequently this procedure is stipulated by the automobile industry and also transferred to its suppliers, however sometimes without specifying clear and concrete limit-values. This leads in the practice to a situation where the allowable limit-values may again be relaxed, in order to avoid receiving unnecessary error-messages on the installed equipment.

It should therefore always be part of the planning process, to question which concrete error-conditions have to be obtained by certain supervisory processes. Our system recognizes virtually all errors through a combination of standard controls, including driver-start, torque-control, mechanical shut-off clutch and an accurate and precise built-in-depth-sensor having a very high repeatability.

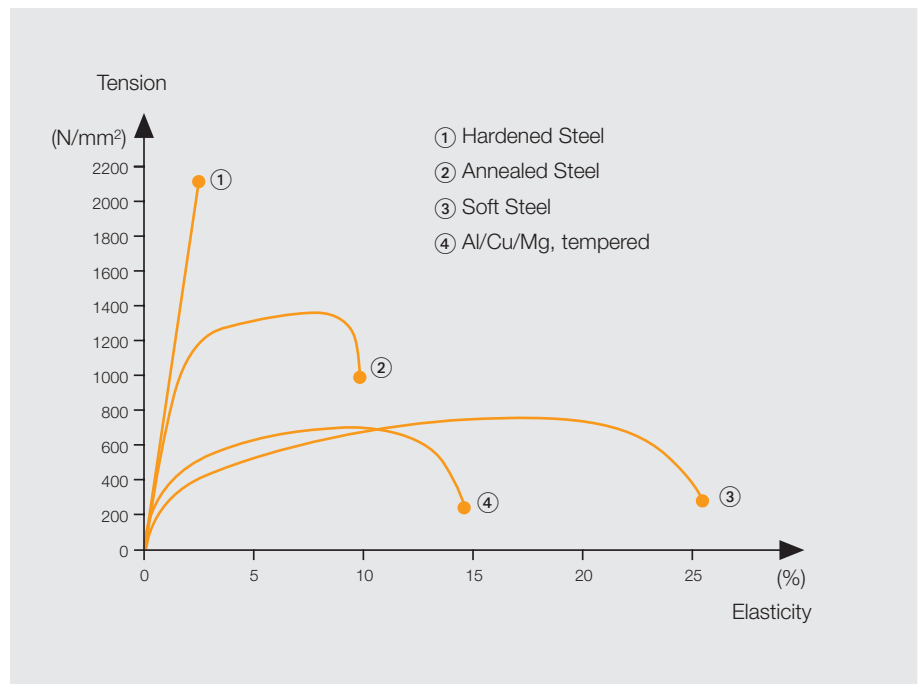


Picture 7: Angle-Controlled Tightening

### 1.3 Angle-Controlled Tightening

When using the so-called angle-controlled tightening process, both torque and angle are used as the controlling factor. Here, the angle and not the torque is used during the final process. This means that the screw is being tightened to a predetermined trigger torque value and then further rotated by a predetermined post-tension angle. This procedure is an extremely rare application-case, which only finds use where a screw moves into its plastic deformation. If this is the case, the screw leads practically to no considerable torque increase, so that torque cannot be used as the controlling factor.

For the tightening of a screw into its plastic deformation, specifically detailed parameters must be kept. Moreover, the screw loses its reusability, since it is being deformed during tightening. Consequently, this procedure only finds use within quite particular safety applications.



Picture 8: Hooke's Tension-/Elasticity-Diagram

Maybe at this time, we should clarify the concept "plastic" and "elastic" by looking at the so-called Hooke's Tension-/Elasticity-Diagram. One can recognize on the X-axis the tension and on the Y-axis the elasticity of the screw. The pre-load strength is proportional to the applied torque, assuming that the friction values are constant.

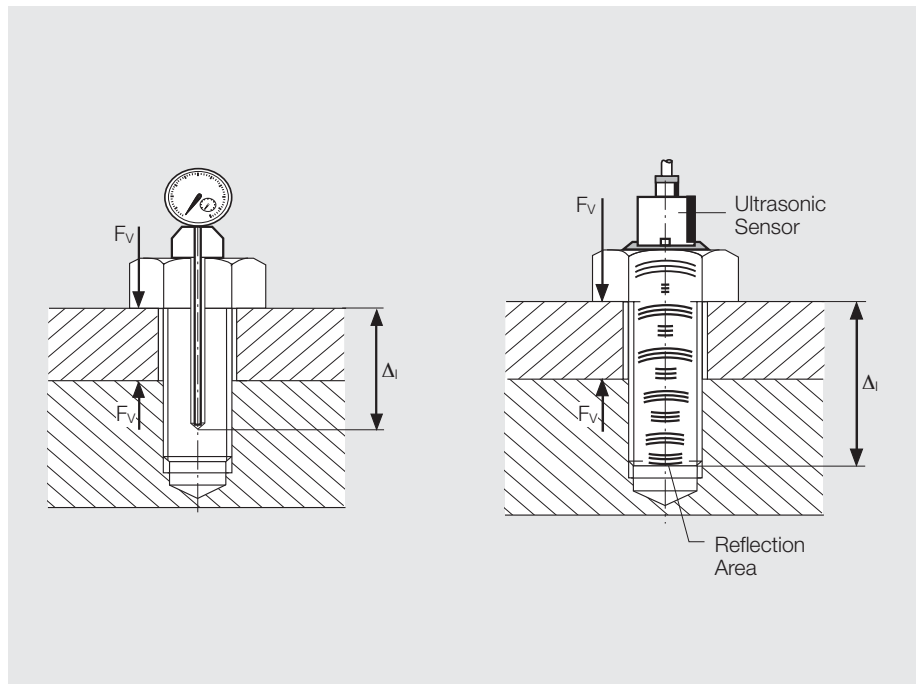
It is easily recognizable, that first the elasticity increases proportionally to the climbing torque. This area is called elastic distortion, since after retraction of the load (pre-load/torque) the distortion retracts as well.

By reaching the tension limit of the screw, the smooth increase of the screw levels off and the so-called plastic area of the deterioration is reached, which will not retract once the load is reduced. After overstepping the maximum load, the forming of the screw starts and the diagram ends with the breakage of the screw.

According to a design of the screw, this plastic area is very short or flat and elongated. One can easily recognize that a special screw with a wide plastic area is necessary to realistically apply an angle-controlled tightening process. With this particular procedure, friction influenced errors may be eliminated and the load capacity of the screw can be extended to its max. There is however no possibility to reuse the screw connection.

To restate this process again clearly: less experienced customers frequently request an angle-controlled process without fulfilling the necessary prerequisites, such as using a screw with sufficient tension. Even though the procedure can be theoretically accomplished, it in fact brings no advantages when compared with the torque-controlled procedure.





Picture 10: Length Measurement

### 1.5 Ultrasonic Length Measurement

The mathematical context between the tension of the screw and the created pre-load is much more accurate than the connection between the torque and the pre-load. A direct tension measurement leads to a much more accurate pre-load value. This can be accomplished by the mechanical measurement of a bore in the screw, which must be deeper than the clamping length of the used screw. However, this method is only suitable for special cases using large screws and it practically does not find many applications.

Another method is to acquire a screw's tension using the time-measurement of an ultrasonic wave.

To this an ultrasound-impulse is brought into the screw-head. The impulse multiplies throughout the screw, reflects on the shaft-end of the limit-surface steel/air and returns back to the screw-head. The time-difference between the first and second echo of the impulse is used to measure the screw length. This measurement can be high-frequency, so that a high dissolution can be reached with several thousand measurements per second.

Different tension conditions of the screw-material, as well as the temperature of the screw must still be compensated.

This procedure has already been developed for series production of extreme sensitive safety screw-connections in the automotive industry. Still, even with this procedure, it is necessary to additionally supervise torque and angle.

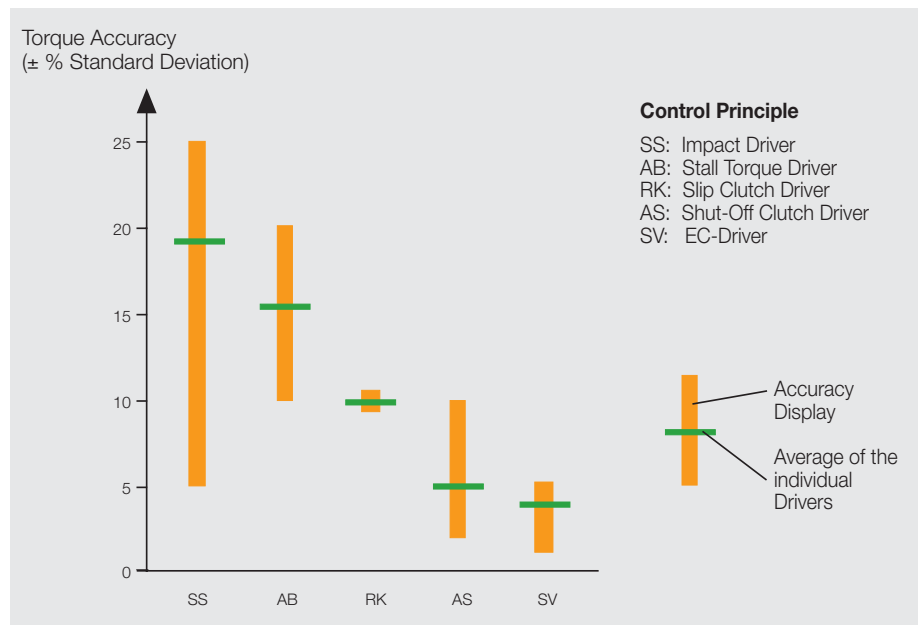
It is our opinion that this procedure will hardly be a generally accepted operation, since only special screws can be used with an integrated sensor. Consequently, with each processed screw, an expensive sensor-element remains inside the assembled part.

## 1.6 Special Cases

All previously described proceedings only apply to metric screw-connection into steel. In the practice, there is a multitude of screw-connections, especially sheet metal assemblies, self-drilling or self-forming screws as well as screw-connections with metallic screws in thermoplastic or thermo-setting plastics. It should be pointed out at this time that special tightening requirements apply for those assembly cases. In principle there is also a connection between obtained torque, friction values and the generated assembly pre-load. However, because of very different product material-characteristics, the context cannot be taken care of by the screw material-characteristics alone. With self-drilling or self-forming screws, additional error variables occur, requiring a so-called insertion torque.

Here, the constructively correct design of the screw-connection is very important. With the tightening of thread-forming and thread-cutting screws, high driving torque-values are necessary. These driving torque-values occur close to the seating torque-value. Only when the screw-connection is designed so that after the forming of the thread and prior to seating of the screw head, a free run-through is guaranteed, then the displayed connections of the torque-controlled tightening diagram apply. It is however important that the torque shut-off is bridged during the driving of the screw, so that a premature shut-off of the screwdriver is avoided. Such a specialized tool is our Sensomat Screwdriver, which is available as a handheld- and stationary tool.

In other cases, where for example a thread is molded into a blind hole, it is necessary to not only achieve a final-torque but to also consider friction values and especially thread-forming values. Because of large fluctuations of the driving torque, the remaining inaccuracies of the obtained pre-load are in any case far higher than in the previously described standard cases. Especially with direct-drive into thermo-setting plastics, the right screwdriver speed is of great significance.



Picture 11: Torque Accuracy Display of Screwdrivers

## 2. Screwdrivers

### 2.1 Handheld

The predominant number of handheld Screwdrivers contains some type of a mechanical torque-control. In the most simplified case, the motor-power or the impact-power restricts the tightening-torque. In the highest development stage, we offer our MICROMAT or MINIMAT Screwdrivers with torque-controlled clutches, which achieve a precision from under  $\pm 3\%$  standard deviation. Picture 11 shows a rough overview of screwdriver specifications. The high torque-precision of  $\pm 3\%$  can only be reached by eliminating the kinetic energy through a particular design of our MICROMAT/MINIMAT-clutch.

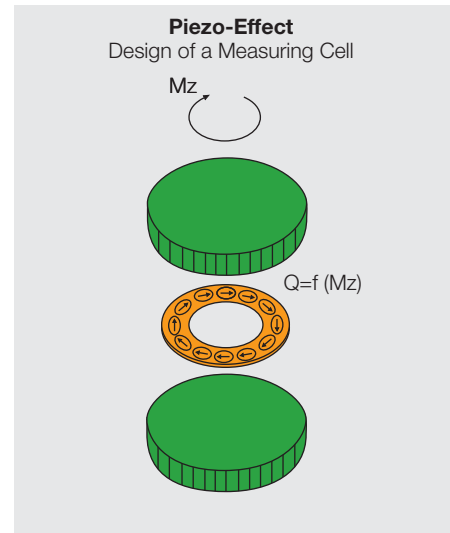
### 2.2 Stationary

Either air-operated screwdrivers with highly accurate shut-off clutches or EC-servo screwdrivers, both in stationary design are available. The use of our MICROMAT or MINIMAT clutches enables a shut-off torque accuracy from under  $\pm 3\%$  standard deviation. If measurements acquisition is required, suitable transducers for either torque or angle are available. However, air-operated shut-off screwdrivers always control the shut-off process mechanically, which means that the measuring process is designed to be of a supervisory kind and not of a control kind.

With the EC-Electric Servo Screwdrivers, the measured unit directly controls the process. According to the measured actual-value, the process is directed to the set point. With it, the measurement accuracy goes directly into the feedback-loop and simultaneously into the assembly result. This method allows an accuracy of less than  $\pm 1\%$  standard deviation. Such a high precision can only be achieved using an extreme slow process management and this weighs heavily on the cycle time. Additionally, such high accuracies cannot be achieved at lower torque values.



Picture 12: DMS-Transducer



Picture 13: Piezo Electric Transducer

### 3. Measuring Technology

#### 3.1 Transducer

##### Eddy Current Transducer

Eddy current transducers were designed to use a sender without wear-parts (slip-ring-transfer). Slotted hollow-cylinders are attached on each end of a torsion-shaft, which creates a variable cylinder surface, once the hollow-cylinders are twisted against each other. Spools are integrated into the surrounding casing, which generate a high-frequency eddy-current field on the cylinder surface. The surface and with it the dampening of the field changes by applying torsion. This dampening is used as the measuring unit.

The relative expensive tuning, the necessarily large size and the price are the main obstacles for this process to widely used. Nevertheless, such transducers are sometimes used for torque measuring of screwdriving applications.

##### DMS – Transducer

The strain gauge (DMS) technology rests on the principle, that a part is mechanically deformed and this deformation is relayed by a meander-formed wire (= DMS-gauge). Through the tensioning of the wire, a varying electric resistance occurs, which consequently represents the measurement of the materials mechanical deformation. This procedure is frequently used for tension and pressure measurement and appears to be simple in its application. To determine a torque value, the DMS-gauge is generally arranged 45-degrees to the torsion axis and the electrical resistance is obtained by using several gauges.

The usable linear area between the torque and the resistance change is not as large as with the piezo-electric transducer, but it is made to correspond with the respective torque-ranges of our Screwdrivers. Because of the rather large spread and many different standard available components, this is a relative low-cost solution.

##### Piezo Electric Transducer

A further possibility for the torque measurement is the use of a piezo-electric transducer. In this process, silicon crystals are elastically deformed, so that an electric load appears on its defined outside surfaces. This load is found to be proportional to the applied force. Torque is measured using the shown ring-element. The single quartz discs are arranged in such a way, that a appearing tangential force can be measured. The transducer carries a high pre-load which allows it to transfer the appearing torque through frictional resistance to the quartz elements. The single elements are arranged parallel, so that the appearing load is proportionally to the transferred torque.

Since the insulation resistance of the charge amplifier and measuring instrument is of a certain size, the occurring load flows only gradually. Piezo-electric transducers are therefore only marginally suited for static measurement. For the use in the screwdriving technology however, the piezo-electric transducer is very well suited because of its extreme high dynamic, an excellent linearity over a wide measuring range, its very small size, the non-existent wear-parts, its high rigidity and the outstanding general measuring qualities. Especially very high sampling rates (10 kHz) allow for the torque acquisition of hard screw-joints. All DEPRAG Measuring-Screwdrivers measure the reaction-torque, so that no measurement of movable parts is required.

The use of piezo-electric torque measurement-cells are particularly well recommended for the use in stationary measuring platforms because of a rather large usable torque-range.

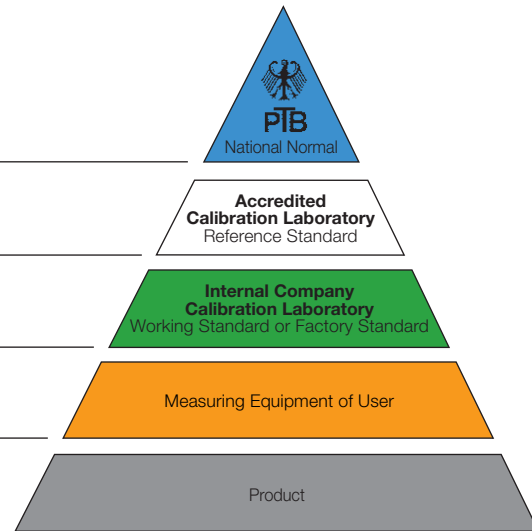
Accredited Laboratory  
Definition of National Norms

Attachment of Reference Test Material to the National Normal  
i.e. Kistler Company, Switzerland (SCS Nr. 049)  
EADS Company (DKD-Reg.-Nr. 01901)

Verification at the manufacturer (DEPRAG)  
with Reference Test Material in the calibration laboratory

Verification at the user (customer)  
with Reference Test Material

Components of the measuring chain:  
Screwdriver, Measuring Platform, Measuring Instrument, etc.



Picture 14: Calibrating-Hierarchy

### 3.2 Calibration

One important requirement of the quality assurance system is the traceability of a measuring instrument to national standards. This demand is generally based on ISO 9000 requirements. The traceability is given, if a measuring instrument or measuring system was calibrated in an uninterrupted chain using a reference, which in turn is traceable to national standard.

Following are some important definitions:

**Testing:** determining, if a demand is fulfilled. Example: an air-operated shut-off screwdriver is torque tested against a torque transducer. If a deviation is detected, the Screwdriver must be readjusted.

**Adjustment:** change made to the measuring instrument to eliminate a systematic measuring deviation.

**Certification:** testing of a measuring system to agree with the calibration laws as required by the consumer protection agency. This includes checking whether the size of the measuring deviation of each instrument does not exceed the allowable error limits. Thereafter the measuring instrument will be certified by the testing agency or its representative. The calibration law clearly states which measuring instrument needs to be calibrated! (Not to be confused with adjustment or calibration).

#### Standards:

##### Measuring means comparing

A measuring instrument compares something unknown with something known. A measuring instrument needs to be checked, using a calibration process that measures an object with known proportions. If the measuring instrument shows the same value or a value that falls within the allowable tolerance window, then it is ready for certification. A known value is called "Standard". There are standards in different hierarchy steps. These are compared in accordance with a concrete schematic. On top of the hierarchy are normally the national standards. Even the national standards are regularly compared with the corresponding standards of other states.

**Calibration:** comparing a measuring instrument with a reference-measuring-system - under the same conditions - to determine a systematic deviation and to subsequently trace it to national standards. The calibration process always acquires the current actual condition.

**Reference Measuring System:** the applicable standards must be tested and certified by an accredited agency allowing complete traceability.

**Measuring Chain:** the measuring chain comprises all components from the measuring transducer all the way up to the measuring instrument (transducer, cables, measuring instrument).

#### Calibration performed by DEPRAG

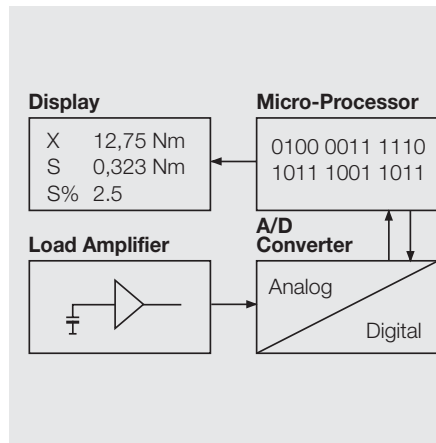
##### Individual Units

Basically, all components of the measuring chain have to be independently calibrated. Measuring instruments for the piezo transducer are calibrated using a charge-calibrator and measuring instruments for the strain-gauge transducer are calibrated using a strain-gauge calibrator. Each one of these instruments is connected over a DKD-calibrator to the national standards of the Federal Agency of Physical Technology and therefore corresponds to the highest possible quality requirement. The transducers are calibrated in specialize calibration-device using traceable reference-measuring systems.

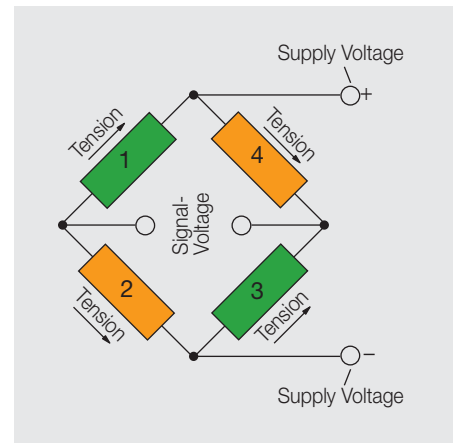
##### Measuring Chain

Alternatively to the calibration of the individual components, we can of course also calibrate the entire measuring chain. This process is advantageous if the minimizing of the deviation is important. The calibration of individual components however allows for interchangeability of those single components.

The customer receives a calibration certificate showing the results of the calibration and also the traceability of the values. The basis of the calibration process are the actual valid standards, which are currently the DIN EN ISO/IEC 17025 (Capability Instructions of Testing- and Calibration Laboratories). Of course, all DEPRAG calibration and text processes fulfill the stated requirements. Our process has been many times tested and confirmed by a process-verification procedure done by a renowned car-manufacturer.



Picture 15: Principal Piezo Control-Diagram



Picture 16: Principal Strain-Gauge Control-Diagram

### 3.3 Measuring Instruments

#### For how long is the calibration valid?

In principle, a calibration is only valid at the time of its performance. The determination of when to perform a calibration is solely the responsibility of the user. The application, which means the conditions of the workplace, the type of usage of the measuring unit, frequency of use and safety requirements of the product to be assembled, decisively influence the required number of calibration intervals. If measuring systems are integrated into the moving assembly process, then it will certainly be more meaningful; to select shorter calibration intervals compared to measuring systems used in a laboratory environment. Test cycles can be significant anywhere from 3 months to approximately 3 years.

In general we recommend checking our measuring systems at least once a year. If disallowed deviations are found, then we recommend having the measuring instrument newly calibrated at DEPRAG.

#### for Piezo Electric Transducers

All used measuring instruments essentially consist of a charge-amplifier, an AD-converter and a display instrument. The charge amplifier converts the load sent by the transducer into an electric voltage, which is then defined by the AD-converter into a concrete measuring value. Especially these two components influence the total accuracy of the measuring instruments. Because of the system conditional drift in the electric load area, the measuring instrument automatically performs a zeropoint adjustment prior to the start of each measurement.

#### for Strain-Gauge Transducers

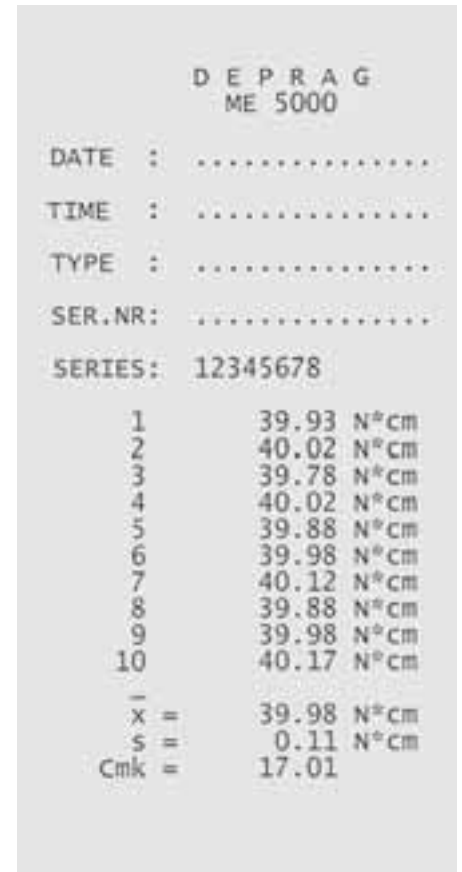
Measuring instruments for strain-gauge transducers acquire the resistance change of the strain-gauge, which is proportional to the torque-change of the submitted measuring range. The measuring-amplifier uses the calibration value to transform the corresponding torque-value and displays the result. The instruments used for the display of values from strain-gauge transducers are finely tuned to the requirements of the transducers. A high precision is possible due to its suitable sampling rate and high dynamic.



Picture 17: Portable Measuring Instrument Model ME 5000 with Docking Station



Picture 18: Stationary Measuring Instrument Model ME 1000



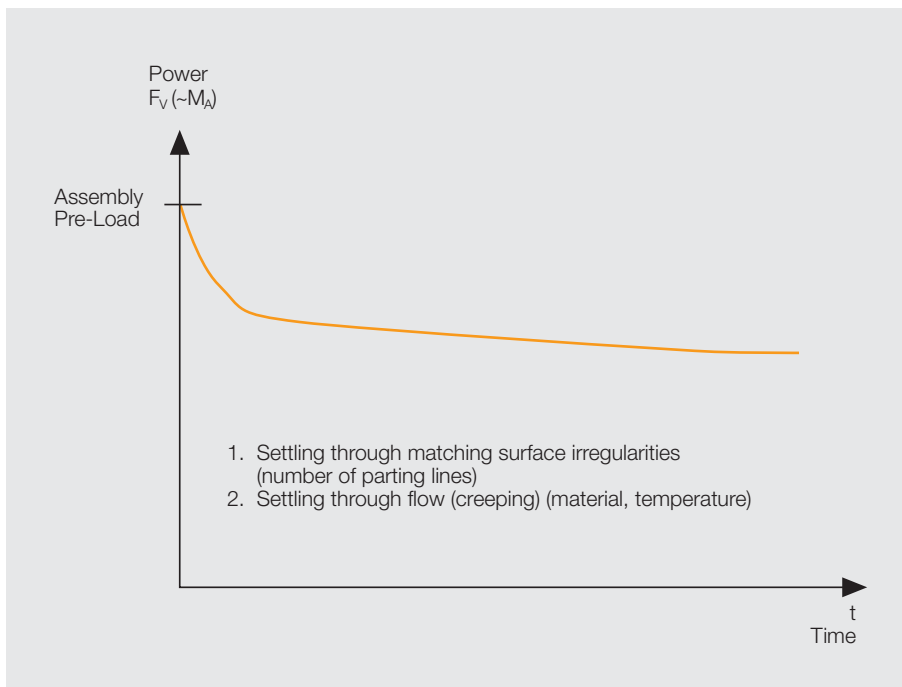
Picture 19: Measuring protocol of a ME 5000

### Handheld Use

We distinguish between measuring instruments for the manual and the stationary use, as well as for transducers based on strain-gauge- or piezo-electric technology. Because of the necessity to perform a zero-point adjustment prior to each measurement, every DEPRAG measuring instrument requires a signal prior to the start of an actual measurement. On all handheld measuring instruments, the Operator manually activates this input. Only if the measuring instrument is in the "Series" mode, then the zeropoint adjustment is executed automatically prior to each measurement. All handheld units are particularly well suited for the testing and adjustment of individual screwdrivers, for a screw-joint evaluation as well as for specific individual measurements. The measuring instrument ME 5000 is a network-independent instrument, which can be used directly on the production line, the DME 200 is particularly well designed for the use in measuring- and adjustment areas, while the DME 200 PC allows the possibility to graphically evaluate a screw-joint on a PC.

### Stationary Use

In contrast to the hand-units, the activation of the stationary measurement is done automatically by a PLC, using a provided comport. Besides the acquisition of the major measuring conditions, such as torque and angle, these units offer extensive statistical evaluation and display possibilities. Our standard solution is the Model ME 1000. Additionally, it is also possible to monitor and document the angle, provided the screwdriver is equipped with a suitable angle encoder.



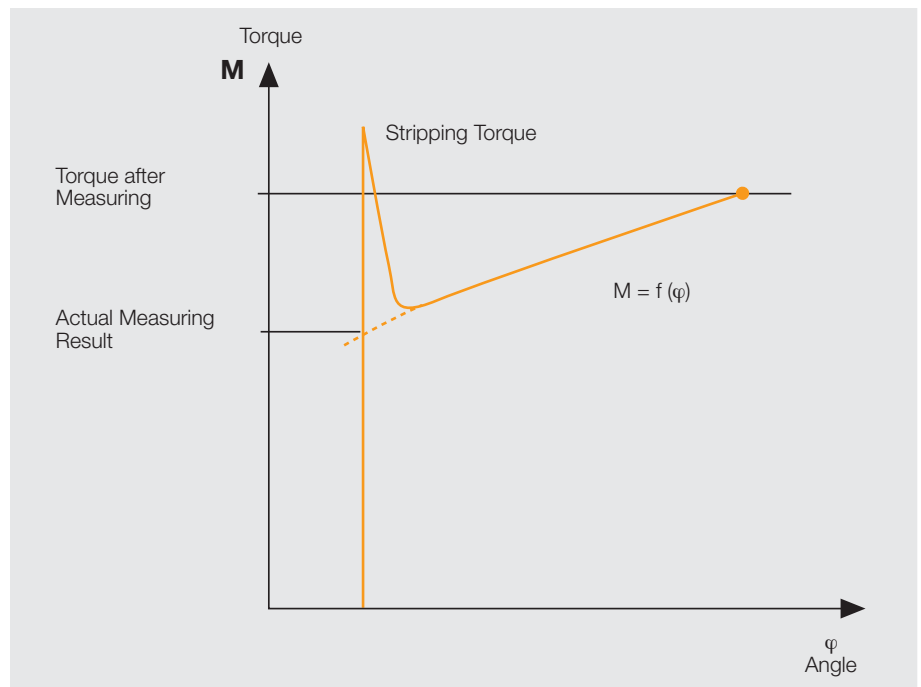
Picture 20: Seating Processes

### 3.4 Seating Processes

Every tightening- or measuring procedure generally only considers the actual torque or pre-load created by the tightening process. However, as previously described in the diagram "pre-load", almost in every screw-connection there is a settling of the joint, which reduces the applied torque as well as the pre-load. This situation frequently leads to problems with the quality control on screwdriving stations. Only in very rare cases is it possible to precisely calculate these settling conditions. Almost always will it be necessary to perform a detailed and costly material analysis using original parts.

Especially if accuracy guarantees have to be given with the delivery of assembly stations, it is only possible to primarily talk about the torque applied by our screwdriving technology. In how far these torque values apply at a later time to the product to be assembled strongly depends on the execution of the entire screw-connection. A multitude of screw-connections has shown that the majority of the settling occurs during the first millisecond after tightening.

This means, that an improvement can be achieved in some cases by lowering the driver speed, since the tightening process is lengthened and the bulk of the settling has already occurred during tightening. If this measure is not sufficient, there is also the possibility of a multi-stage tightening process. In such a case it is possible to tighten the fastener to about 80 % of the final torque, then apply a short waiting period and consequently tighten the fastener to the required final torque. It is practically possible to use any combination of pre-torquing, waiting, loosening of the connection and renewed tightening. A suitable procedure can only be experimentally, because in the practice it virtually always leads to disadvantages with the cycle-time of the screwdriving station.



Picture 21: Retightening of a screw-connection

### 3.5 Retightening of a Screw Connection

In an exact guarantee in regards to accuracy is required, then it is necessary to clearly define the corresponding measuring procedure. The evaluation of a settling condition can in effect only be accomplished by re-tightening the screw-connection. Also, it is imperative to use exact and identically repeatable measuring methods to obtain accurate results. For example, the time of the re-tightening and the selection of the required measuring technology have to be clearly determined. Principally, the re-tightening process requires exact measurements that can only be performed using a suitable measuring instrument, such as our Model DME 200 PC in connection with a torque wrench. Mechanical torque wrenches are inappropriate, because they are much too inaccurate.

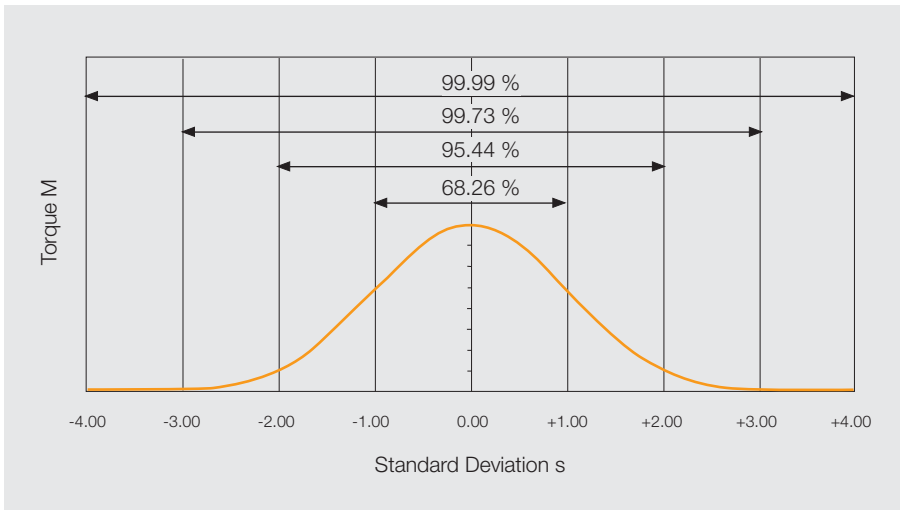
The entire re-torquing process must be documented.

Only after an evaluation of the re-torquing process will it be possible to reconsider the original torque value. Normally, a resting connection results into a higher static friction coefficient, which can be measured using a mechanical torque wrench. Thereafter, the connection goes through so-called Stick-Slip-Effect where the torque is reduced. Only after another linear increase of the connection is it possible to recapture the original torque.

With all measuring technical problems, this is still a very effective quality control method. It is important, to become familiar with this procedure, since it may also be used for other tasks, such as the fine-adjustment of pulse tools.

Once again:

Mechanical torque wrenches can only be used to recognize a primary assessment and they cannot replace an exact measurement.



Picture 22: Gaussian Standard Distribution

## 4. Statistics

### 4.1 Statistical Basis

To retain an equal and permanent production quality, exact production means as well as suitable control-mechanisms are necessary. Through new and stricter regulations in the product liability area, the requirements in regards to quality documentation will continue to rise. Especially the car industry has taken on a forerunner role in this matter and has enforced its numerous suppliers to take similar measures. This documentation measure applies in particular to our screwdriving technology.

Besides the need to display a selection of suitable measuring units (torque, angle, depth, etc.) it is also necessary to statistically evaluate the assembly results. The information provided in this section, should be helpful to clarify the statistics concepts and simplify understanding its results.

There are several mathematical distribution models. The screw-assemblies can be easily displayed using the well-known Gaussian standard distribution, which has the advantage that this method is well known and requires relative simple mathematics. Picture 22 shows a corresponding curve example.

#### Average:

The average value of a measurement series can be defined as an arithmetic or geometrical value. In this connection, the arithmetical value  $\bar{x}$  is always calculated according to the following formula:

$$\bar{x} = \frac{1}{n} \cdot \sum_{i=1}^n x_i$$

#### Measurement Row:

The measurement row is a series of measuring values, which are determined using identical conditions. To obtain a statistical statement, a test series of a minimum of 10 values is required; however using 50 values is even better.

#### Standard Deviation:

The standard deviation of a test series is determined by the average difference of individual measuring values in connection to the calculated average value. The standard deviation  $s$  is calculated according to the following formula:

$$s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n - 1}}$$

Since the standard deviation is stated as an absolute value, the value-range which is limited by the standard-deviation, must always understood an  $\pm$  interval.

Usually, the precision of a measuring instrument or a tool is indicated using a relative standard deviation. This relative standard deviation is of primary importance when derive additional statistical sizes.

#### Understanding the characteristics of the standard deviation:

The average value of a measuring series is the value, which in all probability comes closest to the actual value.

This statement is only valid if an adequately large number of measuring values have been used. In the practical application, the number of 10 measuring values has shown to be the minimum requirement. If a measuring series acquires solely the random errors, then the distribution of the results fall within the Gaussian standard deviation. According the distribution curve, the following statement can be made because of the mathematical context:

68.26 % of all measurements will be in a range of  $\pm 1 s$ ;  
 95.44 % of all measurements will be in a range of  $\pm 2 s$ ;  
 99.73 % of all measurements will be in a range of  $\pm 3 s$ ;  
 99.99 % of all measurements will be in a range of  $\pm 4 s$ ;

All these statements can indicate a certain probability only, never an absolute.

At this time, we like to further clarify the well-known fact that DEPRAG guarantees a  $\pm 3 \%$  torque accuracy. The value of 3 % is calculated as a percentage statement from the standard deviation by referencing the applicable average value. Practical tests have however shown, that in many assembly cases this accuracy value is actually lower than 3 %.

$C_{mk}$	$\bar{x} - UGW$ and $OGW - \bar{x}$	Within Tolerance	Error Portion
0.33	1 s	68.26 %	> 30 %
0.67	2 s	95.44 %	5 %
1	3 s	99.73 %	0.3 %
1.33	4 s	99.994 %	60 ppm
1.63	4.891 s	99.9999 %	1 ppm
1.67	5 s	99.99994 %	0.6 ppm
2	6 s	100 %	$2 \cdot 10^{-9}$

Picture 23: connection of different statistical parameter

## 4.2 Capability Study

Is it necessary to assign a high importance to the capability study concept, because of the development of the quality-assurance procedures and preventive quality assurances. These statistical methods have a goal, to oversee the manufacturing process during production. An important item of such a study is the determination if the used production machine is even suitable for the production process. Such a study is termed a machine-capability or short-term capability. The used index is designated  $C_m$  and  $C_{mk}$ , and it confirms whether the required quality characteristics can be kept within pre-determined limits.

For screw assemblies, torque is the crucial unit. In order to give a torque statement, it is necessary to keep the different influencing factors of the assembly process consistent. Consequently a reproducible measuring setup was defined, which has validity for every capability study performed on our screwdrivers. Since only the influence of the machine with its components has to be evaluated in regards to the machine capability study, this study is generally based on 50 measuring values, which have been taken without interruption and under optimal conditions.

The calculation of the machine capability uses the following formula:

$$C_m = \frac{OGW - UGW}{6 \cdot s}$$

$$C_{mk} = \text{MIN} \left( \frac{OGW - \bar{x}}{3 \cdot s} ; \frac{\bar{x} - UGW}{3 \cdot s} \right)$$

- $C_m$ : Machine capability index
- $C_{mk}$ : Machine capability index
- OGW: upper limit
- UGW: lower limit
- x: Average of the measuring series
- s: Standard deviation of the measuring series

The objective is to reach a  $C_{mk}$  value of 1.67 or higher, since this value is currently demanded by most of our customers. As can be seen on the  $C_{mk}$  calculation formula, a dependence exists between the required limit values (upper and lower limit), the standard deviation s and that machine capability index  $C_{mk}$ . Picture 23 indicates which of the values result from an ideal symmetrical distribution in connection with the standard distribution and it also shows the theoretical error portion.

How are these values to be interpreted? The value of  $C_{mk}$  is an accordance with above shown table a probability value for the number of incorrect assemblies, which fall outside of the required tolerance. So, if the  $C_{mk}$ -value is 1.63 then there is only one incorrect assembly out of a total of one Million assemblies. Additionally, the table shows which driver tolerance is necessary with a maximum  $s = 3\%$  standard deviation, to achieve a  $C_{mk}$ -value of 1.67.

A tolerance of 5 s, which means  $5 \cdot 3\% = 15\%$ , is shown. Consequently the standard deviation of the screwdriver is the most important quality characteristics in regards to the machine capability study.

These machine capability studies are documented in a detailed protocol with statements in regards to capability index, histogram and measuring value sequence.

To evaluate and specify the capability of screwdrivers and to offer our screwdrivers with these specifications, we subject new driver models a laboratory condition study in reference to VDI/VDE 2467. This guideline describes in connection with the ISO 5393 a test procedure, which is being used by German car manufacturers for the homologous tests.

With this procedure the test conditions are specified within extreme small limits, for example "hard and soft" joints are defined within the torque stage to temperature, nominal entry condition or pre-determined inlet pressure and testing has to be done in regards to these classifications many hundred of times.

Each individual test cycle is documented and at the end all studies are included in the total evaluation.

The test-device must have special qualifications. As measuring chain, it may only show a measuring uncertainty according to class 1 of DIN 51309. The measuring instrument capability has to be in accordance with class 0.2 of DIN 51309 of a calibrated measuring chain and it has to be statistically checked once every year.

### 4.3 How accurate is accurate?

An intensive discussion is ongoing about a required, necessary, meaningful and attainable accuracy in the assembly process. We try to specify some concepts:

#### What does Accuracy mean?

First, it is necessary to differentiate between a qualifying accuracy and the accuracy definition according to DIN 55350. The last defines accuracy as "qualitative term for the approximate volume of determined results to the relative value (...)", which means as a non-quantifying volume. In the practical discussion however, accuracy is always meant as a precision concept, especially when assembly is made to torque. Other values, such as angle, distance or time, or even the total process may be termed accuracy. If concrete values are named, then is always recommended to indicate the relative standard deviation of a measuring series. Indicating a number value corresponds with the measuring technical concept "inaccuracy".

For example: Torque shut-off value of 9 Nm with a precision (inaccuracy) from 3 % means, that the tool was subjected to a measuring series with an average of 9 Nm and a standard deviation of  $\pm 3$  % in reference to the average of the measuring result.

According to the DIN (ISO) norm, only measuring values may be used that were achieved under perfect test conditions.

#### Repeatability:

The conversational concept of the repeatability is defined as precision in accordance to DIN 55350 as "qualitative name for the value of the equal approach of independent evaluation results with multiple applications of a fixed evaluation procedure under pre-determined conditions."

Basically, the statement of accuracy – according to the above explanation – is always repeatability, since an average value (set-value) is determined using an accuracy (inaccuracy) of 3 % standard deviation from a series of independent measuring values. In the practice, the verified repeatability is again influenced by different parameters:

#### Design of the mechanical shut-off

According to the wear – and friction connection as well as settling conditions of the clutch, it is possible that the mechanical shut-off is slightly influenced. Therefore a cyclic testing of the achieved torque value is practical.

#### Kinetic Energy

The kinetic energy during an assembly depends primarily on the speed of the used screwdriver. A slower screwdriver causes the movements in the clutch to slow down and therefore it also reduces the dynamic effect. According to our experience, slower screwdrivers have a lower standard deviation than faster screwdrivers.

#### Measuring Technology

The measuring technology used for the dynamic process of the screw-assembly must be well suited for this task, which means it needs a tough rigidity to vibrations, incorporates filters as well as a suitable algorithm to display the accurate measuring value. Additionally, the drift of the measuring instrument has to be taken into account.

Particular attention has to be given to the sampling rates of the measuring instrument, because highly dynamic screwdriving processes require measuring frequencies of  $> 10,000$  Hz.

Many readily available instruments however have sampling rates well below this value! Because of insufficient sampling rates, the deviation may be 10 % and more.

### **Absolute Accuracy:**

The absolute precision of the Screwdriver as well as the Measuring Instrument is independent from the repeatability, important as well. Generally it is only possible to obtain an absolute accuracy for measuring instruments, if they are traceable to national norms. The screw joint can influence the absolute accuracy of the screwdriver. Because of the above-described effect of the kinetic energy, the same screwdriver may obtain different absolute accuracies. According to the construction of the clutch, the design of the screwdriving-station (moving masses after the clutch) and the rise of the torque curve, rather large and changing absolute accuracies may occur. Because of the special construction of our MICROMAT- and MINIMAT-clutches, the Screwdriver itself eliminates these influences, so that there are practically no fluctuations.

Also, when directly comparing two measuring systems, there will practically always be a difference in values. Assemblies with hard joints, high speeds, different measuring filters, electronic and mechanical dampening devices, will influence the accuracy especially during assemblies with high frequency cycles. Therefore, it is possible that during the direct comparison between two measuring systems a deviation occurs.

Generally, the point of reference of an absolute accuracy is given by the tractability of individual measuring systems. However in the practice, the accurate test conditions of these calibration procedures are insufficient. Often, only static calibrations (DIN 51309) are performed and documented and the influence of a highly dynamic screw-driving process will not be considered.

Because of the need for absolute accuracy, the calibration certificate indicates the measuring uncertainty and points out where the measuring values are located in the tolerance field.

### **Which torque values are determined?**

Of higher importance is the layout of the different measuring transducer and its influence of the absolute values of the screwdriver. Primarily, it is important to observe which value has to be measured and compared. Integrated screwdrivers transducers, such as our C-Spindles having an integrated measuring cell, can always measure only the torque supplied by the screwdriver. If this value is being transmitted as pre-load or friction, cannot be determined by the sensor. For clarification, it is necessary to re-check the screw-connection.

An exact re-checking is only possible using a measuring electronic, which give true information about the transition of slip- and slide friction. The breakaway torque will never give a reliable statement in regards to the achieved pre-load. Also, during re-checking, the actually determined value is changed once again, which worsens the accuracy even more.

With making comparison measurements, there will always be deviations. Settling conditions of the screw-connection are the main cause. Furthermore, there are always different dynamic influences when comparing re-checked values with the original values. Deviations of 10 % are about normal.

## 5. Maintenance, Upkeep, Service

### 5.1 Screwdriver

#### Air-Operated Screwdriver

A high availability are today more important than ever. When using air-operated screwdrivers, it is important to supply quality compressed air, use the correct operating pressure and apply correct lubrication. Please refer in this matter to the application operating instruction booklet or read our special leaflet No. D 0090 E in regards to the Maintenance and Upkeep or Air-Operated Screwdrivers.

#### EC-Electric-Screwdriver

The EC-Electric Screwdriver incorporated a maintenance-free, brushless drive. The controller recognizes errors of the measuring systems for torque and angle automatically. If needed, these functions can also be checked by the test functions in the controller menu.

An impairment of the function through gearing wear and tear is only expected after a long operational duration and when using the screwdriver with a high load. Generally, worn gears may be determined during calibration of the tool.

In regular intervals (see also page 16 "How long is the calibration valid"?) a checkup of the driver's shut-off accuracy is recommended. If an inadmissible fluctuation is found, we recommend to have the screwdriver recalibrated in house at DEPRAG.

The maintenance interval for the driver strongly depends on the operational conditions in regards to speed and torque and can therefore not be easily determined.

An interval estimation may be calculated using the following reference screwdriving cycle:

Pre-tightening: 1 second with maximum speed (conforms to 10 rotations at 600 rpm), tightening torque <10 % of the maximum torque capacity of the screwdriver.

Final tightening: 0.5 seconds tightening with approximately 10 % of the maximum possible speed (corresponds to 1 rotation).

Under these conditions, the maintenance interval amounts to approximately 2 million assemblies.

Operators should regularly evaluate the correct connection of the cables.

When exchanging or calibrating the screwdriver, make sure to keep in mind that it is necessary to again input the necessary spindle data, such as offset value and calibration value.

### 5.2 Measuring Transducer

Measuring Transducers are generally maintenance free.

With different operators using the system, it is important to keep the connection plug clean, not to kink the cable and to slide the protection-cap over the plug during transport.

Use only the DEPRAG supplied connection cable.

### 5.3 Measuring Instrument

Measuring Instruments are maintenance free as well. Keep connection plug and instrument clean. We recommend to send the measuring instrument, cable and transducer once a year to DEPRAG for calibration.

## 5.4 Screw Joint Analysis

### Standard Analysis

To determine an assembly process and to establish the optimal shut-off torque of the screwdriver, DEPRAG can perform a screw-joint analysis. For this analysis, we require original parts and screws. In accordance with the analysis results, we can determine the best possible type of screwdriver to be used [EC-Electric or Piezo-Driver] for the screwdriving process, since the analysis evaluations factors such as materials of the connective parts, perhaps washers, type of screw, required processing time, direct-drive, etc. The analysis assimilates the customer's assembly conditions.

Then the screw is tightened using a screwdriver and a torque that is way above the expected value, so that the assembly is being overloaded and the connection is damaged. According to the constructive layout of the screw connection, the screw is damaged or the thread is stripped. With this process, the torque, cycle time and angle can be acquired, displayed and saved. Thereafter, the torque is displayed in a diagram.

Using the curve sequence, it is now easy to judge the assembly sequence and to use the optimal process parameters to select the correct driver.

### Special Analysis

Here, we offer a re-tightening procedure. The screw-assembly to be tested will be tightened with a higher torque and additionally we turn the fastener using a corresponding angle. With this procedure, we can determine and analyze the breakaway torque, the actually applied torque as well as the settling conditions, with a graphical display.

After completion of the analysis, we produce an extensive documentation, which contains not only the measuring values and diagrams, but also includes the analysis results.

We not only perform screw-joint analysis to determine the screwdriving parameters for a DEPRAG designed assembly machine, but also offer this analysis as a service to our customers.

## 5.5 Service Offers

Below is a list of our numerous Service Offers:

- Torque Adjustment on Screwdriver
- Screw Joint Analysis
- Machine Capability Study
- Manufacturer Test Certificate  
Air-Operated Piezo Screwdriver
- Calibration of Transducers
- Calibration of Measuring Instruments
- Factory Calibration of a Measuring Chain
- Torque RE-Checking of Screwdrivers
- Testing of the Calibration – Screwdriver
- Factory Calibration – Screwdriver
- Power Analysis – Performance Test
- Training – in House  
Maintenance of Air-Screwdrivers,  
Screwfeeding Machines and/or  
EC-Electric Screwdriving Systems
- Training – at customer  
Training from individual  
Components to the assembly station
- Maintenance and Upkeep at customer

For more details, please contact our service department at +49 (0) 700 00 371 371, at any time.

## 6. Summary

The complete problem area of process accuracy, measuring technology and statistics on an automatic assembly is multifaceted and complex.

We have tried to clarify with this leaflet major concepts and statements. Generally, we can reduce the content of this leaflet to the statement that we guarantee the accuracy of our Screwdrivers to be within 3 % standard deviation. In many cases we have achieved even better accuracies and in some cases there have been worse accuracies.

We have shown our competence in this field in many instances and have also found excellent solutions using appropriate investments. We welcome your questions, combined measuring procedures, screw-joint analysis and other extensive testing procedures.

## 7. Literature and Standards

1. Ruppelt, E.;  
Compressed Air Handbook  
Vulkan-Verlag, Essen, 1996  
ISBN: 3-8027-2692-8
2. Bauer, C. O.;  
Handbook of the Fastening Technology  
Carl Hanser Verlag, München, Wien, 1991  
ISBN: 3-446-14609-1
3. ICS,  
Automatic Screwdriver Assembly  
Hans-Herbert Mönning Verlag Iserlohn, 2003  
ISBN: 3-922 885-64-0
4. German DKD-4 Calibration Service,  
Traceability of Test Instruments to  
National Standards
5. DGQ-Text 16-31  
SPC 1 – Statistical Process Guidelines
6. DGQ-Text 16-33  
SPC 3 – Introduction to the Statistical Process (SPC)
7. DIN 1319 T3  
Base Concept of the measuring  
technology
8. DIN 51309  
Calibration – Torque Measuring Instruments for static torque, 1998-2
9. DIN 53804 T1  
Statistical Analysis
10. DIN 55302  
Statistical Analysis Process
11. DIN 55350  
Concepts of quality assurance and  
Statistics
12. ISO 5393  
Rotary tools for threaded Fasteners –  
performance test method
13. ISO 6789  
Assembly tools for screws and nuts;  
hand torque tools, requirement
14. VDI 2230  
Systematic Calculation of high-frequency  
screw-connections
15. VDI 2862  
Use of Screwdriving Systems in the  
automotive industry, 1999-7
16. DIN EN ISO/IEC 17025  
General Requirement on the competence  
of test and Calibration Laboratories
17. VDI/VDE 2646 (Draft)  
Instructions for the traceable  
Manufacturers Calibration
18. VDI/VDE 2647 (Draft)  
Instructions for the dynamic  
Testing of Tools

# DEPRAG

**DEPRAG SCHULZ GMBH u. CO.**

P.O. Box 1352, D-92203 Amberg, Germany  
Kurfürstenring 12-18, D-92224 Amberg  
Phone (0 96 21) 371-0, Fax (096 21) 371-120  
[www.deprag.com](http://www.deprag.com)  
[info@deprag.de](mailto:info@deprag.de)



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